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An Examination of the Threats and Risks to Forests Arising from Invasive Alien Species

Emina Krcmar

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Executive summary

Invasions by alien organisms into new habitats pose one of the most significant global threats to ecosystem biodiversity and serious threats to economies around the globe. Canada, with its vast forests and developed forest sector, is very vulnerable to invasions of newly introduced and already established alien species.

The impacts from and costs of invasive species to forests and the forest sector can be broadly divided into three categories: environmental impacts, timber losses due to reduced tree growth and increased tree mortality, and management and eradication costs. The only existing projection of potential economic impacts to Canadian forest sector gives a range of CAD$7.7 billion to CAD$20.1 billion annually. This cost projection, based on damage histories of alien invaders in sectors other than forestry, is highly variable to the loss rate used; however, the order of magnitude of the projected cost to Canadian forest sector is consistent with the aggregate cost estimates of the impact of invasive alien species to forestry in the U.S., Germany and New Zealand.

Whereas impacts of invasive alien species are primarily local and national, the causes of their introduction and spread are regional and international, and are driven primarily by trade, transport and travel. Major pathways of introductions of alien species that pose risks to forests include wood packaging, trade in nursery stocks, as well as the trade and transport of wood products.

An examination of management options reveals that prevention of introductions is the first and most cost-effective line of defense against invasive alien species. In addition to the high cost of eradication and control treatments in forestry, the application of many control measures is controversial from the public perspective. Prevention of introductions should involve risk analysis for each proposed import of an alien species or commodity.

An analysis of institutional frameworks and existing regulatory systems in Canada, the U.S., the European Union, Australia and New Zealand is undertaken, because the U.S. and European Union are Canada's major trading partners, and Australia and New Zealand are world leaders in the prevention and control of alien invaders. National policies and action plans worldwide are based on international agreements, but they vary because of the costs involved with the prevention of introductions of invasive alien species, and concerns regarding potential disruptions of trade. In the U.S., tools for mapping the potential areas of introduction and spread are used to support prevention and control of forest pest and pathogen introductions. Both Australia and New Zealand have established specific biosecurity agencies to provide science-based risk analyses and policies to protect the countries' ecosystems and economies from invasive alien species. The costs of border inspection in Australia and New Zealand are shared between importers, the forest sector, and federal and state governments.

Although current efforts in many countries, including Canada, for dealing with invasive alien organisms are effective in particular cases, they are not successful in controlling the general problem. Several measures are recommended to improve protection of Canada's forest ecosystems and forest sector from future damage caused by these species:

(1) stringent enforcement of existing regulations;

(2) securing funds for research, enforcement and public education;

(3) providing cost-effective allocation of scarce resources to alternative management options;

(4) collaboration and information sharing across different sectors and between government and non-government agencies;

(5) using existing models and adapting risk assessment protocols;

(6) risk analysis initiated for species from the "white list" vs. "black list," and;

(7) developing education and outreach programs to raise awareness of Canadians about the problem of invasive alien species.

Résumé

L'introduction d'organismes exotiques dans de nouveaux habitats constitue l'un des plus importants dangers, à l'échelle mondiale, en matière de biodiversité des écosystèmes, et pose une sérieuse menace aux économies des quatre coins de la planète. Le Canada, en raison de ses vastes forêts et de son riche secteur forestier, est grandement vulnérable aux invasions d'espèces exotiques nouvelles ou déjà établies.

Les répercussions, sur les forêts et le secteur forestier, des invasions d'espèces exotiques et les coûts inhérents peuvent se diviser en trois catégories : les répercussions environnementales, les pertes en bois dues à la réduction de la croissance et au taux de mortalité des arbres, et les coûts de gestion et d'éradication. La seule prévision existante, concernant les répercussions économiques potentielles sur le secteur forestier du Canada, présente une somme annuelle qui varie de 7,7 milliards à 20,1 milliards de dollars canadiens. Cette prévision de coûts, fondée sur l'historique d'autres secteurs en matière de dommages causés par des espèces exotiques, varie grandement en fonction du taux de perte utilisé; cependant, l'ordre de grandeur des coûts prévus, dans le secteur forestier du Canada, correspond aux prévisions du coût total des répercussions de l'introduction d'espèces exotiques dans le secteur forestier des États-Unis, de l'Allemagne et de la Nouvelle-Zélande.

Les répercussions de l'invasion d'espèces exotiques sont principalement locales et nationales, mais les causes de leur introduction et de leur dispersion sont régionales et internationales, et principalement favorisées par le commerce, le transport et le voyage. Parmi les voies d'introduction des espèces exotiques qui posent un danger pour les forêts, on compte le bois d'emballage, le commerce de produits de pépinière, ainsi que le commerce et le transport de produits du bois.

Un examen des solutions de gestion a révélé que la prévention des introductions constitue le moyen de défense le plus efficace et économique contre les espèces exotiques. En plus du coût élevé des traitements d'éradication et de contrôle en foresterie, de nombreuses mesures de contrôle font l'objet de controverse au sein de la population. La prévention des introductions devrait comporter l'analyse du risque pour chacune des importations d'espèces exotiques ou de marchandises proposées.

Une analyse des cadres institutionnels et des systèmes de réglementation actuels du Canada, des États-Unis, de l'Union européenne, de l'Australie et de la Nouvelle-Zélande est en cours, puisque les États-Unis et l'Union européenne sont d'importants partenaires commerciaux du Canada, et que l'Australie et la Nouvelle-Zélande sont des chefs de file mondiaux en matière de prévention et de contrôle des invasions d'espèces exotiques. À l'échelle mondiale, les politiques et les plans d'action nationaux reposent sur des conventions internationales, mais varient en raison des coûts associés à la prévention des introductions d'espèces exotiques et des inquiétudes quant à la perturbation potentielle du commerce. Aux États-Unis, des outils de cartographie des régions propices aux introductions et à la dispersion facilitent la prévention et le contrôle des introductions de ravageurs et d'agents pathogènes dans les forêts. L'Australie et la Nouvelle-Zélande ont toutes deux établi des agences de biosécurité qui fournissent des analyses de risque et des politiques fondées sur la science afin de protéger leurs écosystèmes et leurs économies respectives contre les introductions d'espèces exotiques. En Australie et en Nouvelle-Zélande, les importateurs, le secteur forestier et les gouvernements nationaux et des États se partagent les coûts reliés à l'inspection frontalière.

Dans de nombreux pays, dont le Canada, les mesures actuelles de traitement des invasions d'organismes exotiques s'avèrent efficaces dans certains cas, mais ne réussissent pas à régler le problème dans son ensemble. On propose plusieurs mesures afin de rehausser la protection du secteur et des écosystèmes forestiers du Canada contre les dommages éventuels causés par ces espèces :

(1) une application rigoureuse des règlements existants;
(2) l'affectation de fonds à la recherche, à l'application et à la sensibilisation du public;
(3) une affectation rentable des ressources limitées à des options de gestion différentes;
(4) la collaboration et le partage de renseignements entre les différents secteurs ainsi qu'entre les organismes gouvernementaux et non gouvernementaux;
(5) l'utilisation de modèles existants et l'adaptation de protocoles d'évaluation du risque;
(6) une analyse du risque fondée sur la « liste blanche » et la « liste noire » des espèces;
(7) l'élaboration de programmes d'éducation et de sensibilisation visant à mieux informer la population canadienne du problème relatif aux invasions d'espèces exotiques.

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Preface

This report reviews problems presented by invasive alien species to forestry and forest ecosystems. The information collected and presented supports integrated, interdisciplinary development of policy for dealing with invasive alien species in the framework of sustainable forest management. Through a general analysis of invasive alien species and the use of specific cases, the report seeks to:

- examine the threats and risks to Canada's forest sector and ecosystems arising from invasive alien species;
- understand both the ecological and economic impacts that invasive alien species have on the forest sector and ecosystems, across the globe and in Canada;
- analyze pathways of introductions and their relationships with trade;
- examine management options for preventing new incursions and for early detection of alien invaders if incursions occur;
- outline institutional frameworks and existing regulatory systems, and identify potential difficulties in addressing invasive alien forest species, and
- identify possible solutions and recommendations that can be used to deal with invasive alien forest species in Canada.

This study started with a search for information that focused on invasive alien species that affect forestry and forest ecosystems economically and ecologically. An extensive literature search covered various aspects of forest-damaging alien species, as well as the literature regarding alien species in general, reasons for their invasiveness, ecological and economic impacts of invasive alien species to forests and the forest sector, and regulatory efforts dealing with invasive alien species. A significant portion of this report resulted from information on invasive alien species from Canadian sources, including publications by the Canadian Forest Service, the Canadian Food Inspection Agency and peer-reviewed publications. Researchers in government laboratories, regulatory agencies and universities provided valuable information via personal communications.

Beginning with a brief overview of invasive alien species introductions, both deliberate and accidental, that pose the greatest threat to forest sector and ecosystems across the world, the report covers all issues of invasive alien forest species, from defining the terminology to recommending policy changes. It addresses the first two stages of an invasion by alien species—introduction and establishment—and the corresponding management options, and examines how the rate of introduction of alien species has increased in accordance with increases in trade volumes. The report outlines the major institutional components for regulating invasive species at the regional and international levels, as well as within several countries, including Canada. It concludes with a broader set of recommendations to minimize risks posed by existing and potential threats to forests posed by invasive alien species.

Each chapter carries a selection of more specific cases illustrating mainly Canadian case studies. The second chapter summarizes outcomes of several national economic impact assessments, including one Canadian study. The 18 cases perform several purposes: they draw attention to specific problems in Canadian and other countries' forests and forest sectors due to introductions of alien pests, provide details, and suggest additional information sources. Each case can be read as a separate, self-contained piece, or in conjunction with the chapter into which it is inserted; some cases cut across individual chapters topics.

The last chapter contains no cases, as it is intended to provide a framework for building new policies, open questions and recommendations.

I wish to acknowledge Bill Wilson, who initiated this study, and Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre (Victoria, British Columbia) for providing financial support. I express thanks to Kees van Kooten, Brian Peter and Laura Lapp for valuable comments on this report.

This report is one of many possible reviews of the threats and risks to forests arising from invasive alien species and presents only the author's perspective.

Emina Krcmar
Vancouver, March 19 2008

1. Introduction: background, definitions and scope

For a considerable time now, the scientific community has called for the recognition of alien species invasions as one of the most serious contemporary ecological problems (Berenbaum 2001; Niemela and Mattson 1996; Liebhold et al. 1995). This issue is considered to be the second greatest threat to biological diversity, after that of habitat loss (Wilcove et al. 1998). Alien invaders threaten almost 20% of world's vulnerable terrestrial vertebrates (MacDonald et al. 1989). Economic and social impacts of alien invaders are also significant. Although governments of many countries recognize the threat posed by invasive alien species, responses to this problem remain inadequate.

Increasing travel and trade across the globe has increased the incidence of species movement from their places of origin to new areas (Mack et al. 2000). The number of species that have entered new ranges has increased by orders of magnitude in the past 500 years and especially in the past 200 years (di Castri 1989). Since the nineteenth century, at least 4,500 species of non-native plants, animals and pathogens have become established in the U.S., and 15% of these are harmful (OTA 1993). Invasions of non-native organisms can be even more severe. In New Zealand, for example, 47% of plant species are non-native (Heywood 1989).

Canada, too, has been invaded by non-native species. These include species native to one part of Canada that have moved into another region of the country, as well as species that come from outside the country. About 5% of mammal species and 27% of vascular plant species in Canada are estimated to be non-indigenous, whereas the number of other types of non-native species in Canada is unknown (Canadian Wildlife Service 2003).

The number of detected introductions of alien organisms into new habitats is climbing. In New Zealand, three introductions of non-native species were detected in 1990; more than 30 were detected in 2003 (Kriticos et al. 2005). The increase in species detections is likely due to increasing volumes of trade and travel, a broadening of trading partners, and improved surveillance and diagnostics.

Definitions

Terminology in this area is not uniformly applied. Different terms are used in the scientific literature to denote "a species being beyond its natural range of potential dispersal" (OTA 1993): these include "alien," "exotic," "foreign," "immigrant," "neophytes," (in the case of plants), "introduced," "non-indigenous," and "non-native." Another widely used term, "biological invasion" or its abbreviation "bio-invasion," refers to "the expansion of a species' geographic range into a new area" (Liebhold et al. 1995).

An alien organism becomes invasive when it can reproduce and increase its range in a new environment, thus involving an increase in population size and a geographical range expansion. Because invasive species often harm economies, ecosystems and society, they are also defined as "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (Clinton 1999).

In this report, we employ "alien" as the most general term for immigrant species—referring to both beneficial and harmful introduced organisms, whereas we use "invasive" to denote for species that may become harmful to economy, ecosystems and society. Alien invasive organisms that cause the most damage to forests are accidentally introduced insects and pathogens, but introduced weeds and woody plants can also be destructive, as they can compete with native forest vegetation for space, nutrients, light and water.

Modern gene technologies pose additional risks to the environment—a concern recognized by the new international agreement, the Cartagena Protocol on Biosafety (CBD 2000), which was adopted as part of the Convention on Biological Diversity. Although an important issue, the threats and potential risks posed by genetically modified organisms are outside the scope of this report.

Measures to prevent introduction of invasive alien species and control their spread come under a collective notion of "biosecurity." The United Nations Food and Agriculture Organization outlines the scope of biosecurity:

> *Biosecurity is composed of three sectors, namely, food safety, plant life and health, and animal life and health. These sectors include food production in relation to food safety, the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and safe management of invasive alien species and genotypes. Biosecurity thus has direct relevance to food safety, the conservation of the environment (including biodiversity) and sustainability of agriculture.*
>
> Source: FAO 2001

Biosecurity seeks to identify, prevent and remedy harm in specific sectors and clearly defines its geographical scope. Most national biosecurity agencies have been established to protect sectors within countries, but they also have developed regulations for responding to globalized risks. These measures are established to meet obligations under international agreements or to take advantage of trade opportunities.

Invasions by alien species

Invasions of new habitats by alien species may cause significant ecological and socioeconomic impacts. There are several explanations as to why alien organisms can be so destructive compared to native species, and why they tend to be so even more today than in the past.

The main reason for alien species' destructiveness is related to their biological characteristics. When introduced to new habitats, alien species operate under ecological conditions where there may be no natural enemies (Case 1.5). In addition, in the case of alien forest insects and pathogens, native host plant species have not evolved defense mechanisms to resist these newcomers.

Another set of factors related to invasiveness of alien species involves environmental conditions. Ecosystems altered by land-use changes or new management practices are more susceptible to invasions by alien species (Mooney and Hobbs 2000) than unaltered ecosystems. Environmental stresses associated with natural disturbances such as another invasive species (Case 2.2) and with human-induced disturbances such as harvesting and climate change can make forests more vulnerable to both native and alien pests. However, successful invasions of undisturbed systems are also common.

Ecosystems with low biological diversity tend to be very susceptible to invasion by alien organisms. Both alien and native insects and diseases have caused greater damage to monoculture plantations than to mixed-tree plantations (Cock 2003; Wittenberg and Cock 2001).

Other important factors affecting invasiveness of alien forest species are whether the host tree is native or non-native within a natural forest or plantation, and within a temperate or tropical forest (Cock 2003; Britton and Sun 2002; E.A. Allen and R.W. Duncan, Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C., personal communication). As seen in commercial plantations around the world, non-native trees have proved to be less resistant to the attacks of native forest pests and diseases than have native trees, putting investment in these plantations at risk. For example, the Asian longhorn beetle, a wood-boring beetle native to China, is affecting non-native plantations in China (Britton and Sun 2002). In the past, the beetle was a secondary pest in China, attacking native maple, poplar, willow, and box elder trees. Under the massive reforestation programs initiated in that country in the early 1980s, various non-native trees, particularly poplars from Europe and North America, were planted. These plantations have been highly susceptible to attacks by the Asian longhorn beetle, which in these plantations behaves as if it were an alien invasive insect.

The progression from immigrant to invader often involves a delay or lag phase. Over time, the species can increase in number until it reaches the bounds of its new range and its population growth rate eases (Mack et al. 2000; Hobbs 2000). This simplified scenario has many variations. Some invasions may go through only a brief lag phase or none at all. On the other hand, many alien species take decades to become abundant and widespread. During the lag phase of an alien species, it can be difficult to predict if it will become invasive (Cousens and Mortimer 1995).

Williamson (1996) distinguishes five phases in a biological invasion. For the purposes of this study, we adopt another classification of biological invasion, consisting of four main phases (see Table 1.1). This classification has more recently been used in reports relating to biological invasions of forests at the international level (Cock 2003; Wittenberg and Cock 2001) and by the U.S. national strategy regarding alien species (USDA FS 2004).

Table 1.1 Phases of an invasion by alien species

	Phase	Definition
I	Introduction or entry	into the new region or country
II	Establishment	through at least one reproductive cycle
III	Integration or naturalization	into the local environment
IV	Spread	characterized by population size and geographic range

Predicting invasiveness

Newly introduced species can devastate ecological processes in forest ecosystems and affect the socioeconomics of forest-based communities and the forest sector. Identifying future invasive forest species and predicting their probable sites for introduction and ranges of distribution are scientifically, economically and practically important objectives.

It is difficult to predict which alien species are likely to cause serious damage if introduced. Many species are minor pests in their area of origin, but can be devastating elsewhere. For example, of six of the most devastating forestry pests introduced to North America, only the European strain of the gypsy moth was known to be invasive in its native range (OTA 1993).

Many ecologists have tried to determine predictors of invasiveness and potential to cause damage to construct lists of common traits shared by successful invaders, but so far such lists are applicable for only a small group of species. A number of factors need to be considered to predict potential invasiveness of an alien species (Williamson 1996):

- One of the strongest single predictors of an alien species is at least one previous record of problems when introduced elsewhere, especially in areas with similar environmental conditions;
- Access to reliable information is critical for assessing potential risk of invasiveness;
- Climatic matching and abundance of native habitat also help to predict invasiveness; however, once outside their native range, many species are known to expand into other habitat types, and;
- Characteristics of a species in its native range are less accurate predictors of invasiveness; these characteristics are more important for determining the rate and extent of spread once a species becomes established in a new territory.

Mechanisms

Many deliberately introduced alien organisms are economically beneficial. These include crop plants, ornamentals, game animals, and livestock. However, invasive alien species can have serious and sometimes irreversible environmental impacts on native ecosystems.

Invasive alien forest species can cause populations of native forest species to decline by defoliating or eating the leaves of many tree species (Case 1.1).

CASE 1.1 Gypsy moth

Gypsy moth *(Lymantria dispar)*, a Eurasian defoliator mainly of deciduous trees, was introduced deliberately from Europe to North America in 1869 for silk production, but escaped and became a major forest pest in North America and a serious threat to urban trees and ornamentals. Gypsy moth prefers all types of oak, but many other hardwood species may be attacked. In 1981, at the peak of its outbreak in North America, the gypsy moth defoliated more than 6 million hectares of forest in the U.S. In 1991, the gypsy moth defoliated 347 415 hectares of hardwood forests in Ontario and, by 1992, it was established throughout all of Ontario. The 100 years from the introduction to North America and the first defoliation in Ontario illustrates the unpredictable character of the pest. Within less than 20 years of its establishment in Canada, it became one of the most widespread among native and non-native pests of Canada's forests.

Source: Krcmar-Nozic et al. 2000b; Nealis and Erb 1993

By changing the structure or composition of a habitat, invasive alien species can make it unsuitable for native species. Dutch elm disease (Case 1.2) and chestnut blight (Case 2.1) are two invasive alien organisms that have completely altered the composition of forest communities in eastern North America.

CASE 1.2 Dutch elm disease

Dutch elm disease, caused by the fungus *Ophiostoma ulmi*, also known as *Ceratocystis ulmi*, was introduced to the U.S. in 1930 from Europe. Its vector, the European elm bark beetle, rapidly spread the disease across the country. Although most American elm trees died years ago, the presence of Dutch elm disease is still evident throughout forests in the eastern U.S. About 46 million elm trees out of 70 million have been killed since the disease's introduction.

Dutch elm disease was introduced to Canada in 1945. It killed 600 000 elm trees in Quebec and 80% of the elm trees in Toronto in one year.

Another form of Dutch elm disease, caused by a different type of fungus that may have been introduced on logs imported from Canada, invaded southern England in the late 1960s. About 17 million out of 23 million elm trees were killed by the 1980s.

Dutch elm disease has caused local elimination of elm trees in many parts of North America and England.

Source: Krcmar-Nozic et al. 2000a; Hubbes 1999; Wallner 1996

Invasive alien species include not just insects and diseases but also plants. In regards to forests, invasive plants—or weeds—can make site preparation for tree planting difficult and can reduce tree growth by competing for nutrients (Case 1.3). Invasive weeds can also affect forestry activities such as thinning and road maintenance and can even increase fire risks. In addition to affecting forest systems, many weed species affect other ecosystems by displacing native vegetation and associated animal diversity, thereby reducing a habitat's biodiversity.

CASE 1.3 Scotch broom

Scotch broom (*Cytisus scoparius*) is native to southern Europe and northern Africa. It was brought to North America as an ornamental, but has spread widely throughout the Pacific Northwest, invading native forests, pastures, parklands and roadsides, and has found its way into the interior of British Columbia. Several characteristics of Scotch broom promote its invasiveness and suppression of native plant species: profuse seed production, rapid vertical growth, adaptability to various ecological niches, and lack of natural enemies.

Studies in New Zealand and Australia have found that Scotch broom inhibited growth of Radiata pine seedlings. A study by Canadian Forest Service researchers demonstrates that Scotch broom competes with and reduces growth of Douglas-fir, a valuable timber tree species in British Columbia. Reduced growth in early stages may prolong the rotation cycle and harvesting costs of Douglas-fir with potentially serious economic consequences.

Source: Prasad 2000

In addition to the threats to forests by alien insects, pathogens and weeds, non-native forest trees also may be invasive and cause problems for native species. The introduction of non-indigenous tree genotypes to areas where native genotypes of the same species exist can cause specific problems—namely, hybridization, or interbreeding between the non-native and native strains (Case 1.4).

CASE 1.4 Hybridization of the black poplar population in the United Kingdom

The black poplar, once a distinctive feature of Britain's lowland river valleys, is now an endangered native tree in Britain. In 1982, the British population of black poplar was estimated at between 2000 and 3000, and it is now particularly rare in lowland England. Several factors have contributed to the decline of this species in its native homeland, among which hybridization is considered the most significant. Since the early eighteenth century, several poplar species have been introduced into Britain, some of which are able to cross-pollinate with native black poplar and have created hybrid stock. The use of cultivated poplars across continental Europe has also created a potential threat to remaining black poplar populations there in the form of introgression (i.e. movement of genes from plantations to natural populations through hybridization).

Source: Raybould and Gray 1993; Cock 2003

Some non-native forest trees are vigorous competitors of native tree species and are considered invasive because of their prevalence in the areas where they had been introduced (Case 1.5).

CASE 1.5 American black cherry

The North American black cherry (*Prunus serotina*) is a tree species that was introduced initially into central Europe as an ornamental and, over the years, was planted to produce timber and to function as windbreaks. By the mid-1980s, it had become an aggressive invasive species in Germany, the Netherlands and Belgium, where it threatens plant diversity and natural growth of indigenous forest tree species.

Recent study suggests that pathogens in American soils inhibit the growth of black cherry trees. Without pathogens, black cherry has prospered and thus invaded Europe. This example supports a hypothesis that alien species do well in non-native habitats because they are able to escape pathogens and competitors.

Source: Reinhart et al. 2003

2. Impacts of invasive alien species

Despite the severe actual and potential impacts that invasive alien species cause, no standardized methodology for quantification of these impacts exists. In order to provide an objective reference regarding the significance of an invasive alien species, evaluation of economic, ecological and social consequences is required. For policy makers and managers, impact measurement can be used when analyzing or ranking major risks posed by invasive alien species. It also can be used to help allocate scarce financial and human resources for research and enforcement of regulations for alien species.

Invasive alien species may affect not only local forests and associated forest sectors and communities: their impacts may be felt across regions or countries. Impacts of invasive alien species are both short and long term.

Short-term economic impacts include the costs of: preventing the entry and spread of alien species, early detection and eradication, and timely and reliable risk assessments.

Significant economic impacts may arise from timber losses due to alien species over both the short and long term. Alien species continue to have significant economic and social effects long after their arrival.

If outbreaks are prolonged, related social effects, such as unemployment, can be significant. In communities affected by infestation, additional negative effects include reduced property values and reduced revenue from tourism and recreation.

Ecological impacts of invasive alien species are usually measured over the long term and at several spatial scales. Long-term ecosystem damages depend on how quickly and completely the systems recover. Ecological impacts may become profound in terms of ecosystem composition, processes and resiliency.

Ecological impacts

Weeds, insects and pathogens are normal components of healthy forest ecosystems, but when their populations increase during outbreaks or remain high over prolonged periods, these species become destructive, causing forest depletion and precipitating changes in food and habitat supplies for wildlife, and in hydrology, forest fire regimes and nutrient cycles. Biological invasions may also change the relationships and abundance of native species within ecosystems. In extreme cases, they may even eliminate native species (Mack et al. 2000). For example, chestnut blight (Case 2.1) virtually eliminated the American chestnut tree from North American forests, and Dutch elm disease (Case 1.2) caused local elimination of elm trees.

CASE 2.1 Destruction of the American chestnut

One of the greatest ecological impacts to eastern North American forests came about because of the introduction and subsequent spread of the pathogen *Cryphonectria parasitica*, which causes chestnut blight. Within several decades of its discovery in New York in 1904, this disease eliminated American chestnut (*Castanea dentata*) across about 81 million hectares, resulting in the altered structure and composition of deciduous forests from Maine to Georgia. The impacts of chestnut loss and altered forest ecosystems on wildlife species remain unknown, except for the crash of squirrel populations and extinction of several moth species. On the other hand, the woodpecker populations increased due to the abundance of food and habitat in dead trees.

Source: Orwig 2002; Ostry 2001; Liebhold et al.1995

Ecological impacts of alien species can be direct or indirect. Direct impacts include: defoliation, reduced tree growth, mortality, changes in the availability of water, nutrients and light, displacement, reduction or elimination of native species, and disruption of insect– or wildlife–plant associations.

Invasive alien forest species can indirectly affect local ecosystems and associated streams and rivers by altering, among other things, the hydrology of an area, the rate of soil erosion, soil chemistry, frequency of wildfire, natural ecological processes such as plant community succession, and native plant–animal associations.

Parker et al. (1999) recommended measuring the ecological impacts of invasive alien species at different ecosystem levels:

- their effects on individual members of an ecosystem (including demographic rates such as mortality and growth);
- their genetic effects (including hybridization);
- their effects on population dynamics within the ecosystem (abundance and population growth);
- their effects on ecological communities (species richness, diversity and trophic structure), and;
- their effects on ecosystem processes (nutrient availability and primary productivity).

Synchronized or successive outbreaks of different invasive organisms have been shown to be particularly damaging and may lead to tree mortality (Case 2.2).

CASE 2.2 Combined impacts of alien white-tailed deer and native defoliators on forests in Quebec

Since their introduction on Anticosti Island (Quebec) in the late 1890s, white-tailed deer (*Odocoileus virginianus*) have detrimentally affected forage plants. A study was undertaken to differentiate the influence of deer browsing from the effects of spruce budworm (*Choristoneura fumiferana*) and hemlock looper (*Lambdina fiscellaria*) on conifer species. Most balsam fir saplings showed signs of browsing, and the combined influence of insect defoliation and deer browsing on fir was evident: it lead to balsam fir sapling mortality in the 1980s and early 1990s.

These combined effects on fir will likely modify the forest composition from balsam fir to white spruce-dominated stands.

Source: Chouinard and Filion 2005

Invasive alien species can cause species to become threatened or rare, and can further endanger species already at risk of extinction. Wilcove et al. (1998) estimated that approximately 42% of all endangered species and about 57% of the endangered plants in the U.S. are threatened by invasive alien species.

CASE 2.3 Butternut canker

The preferred host of butternut canker, a disease caused by the fungus *Sirococcus clavigignenti-juglandacearum*, is the butternut (*Juglans cinerea*) tree, although other members of the walnut family are also susceptible to infection. Damage from this disease was first noted in Wisconsin in 1967, but the disease is believed to have been introduced to North America much earlier. There is no known control for this disease. In some areas of the U.S., as much as 90% of the butternut population is dead, dying or infected.

In Canada, infected trees were found first in southern Ontario, then Quebec and, more recently (1997), in New Brunswick.

As tree species native to North America, butternut populations across the continent have declined dramatically over the past century because of butternut canker. Butternut is now listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as endangered and is at high risk of extinction.

Source: Harrison et al. 1998; Harrison and Hurley 2001

Economic impacts

Invasion by alien species can exact great economic toll. Controlling even a single invader can cost millions of dollars. For example, in 2005, the Forest Pest Management program of the Pennsylvania Department of Conservation and Natural Resources spent US$400 000 of combined state and federal funds on hemlock woolly adelgid suppression and an additional US$250 000 on forest pest surveys and detection on state lands (Pennsylvania Department of Conservation and Natural Resources 2005). No benefits of the management program were reported. An economic loss of approximately CAD$30 million by Manitoba alone because of Dutch elm disease provides a glimpse at the magnitude of the problem Canada faces with regard to invasive alien species (RNT Consulting Inc. 2002).

Although examples of local and regional costs of alien invaders exist, comprehensive data on these costs at the national level are lacking. The combined costs arising from invasive alien species may be significant, with implications for environmental policy and resource management. Several factors contribute to the lack of national impact assessments of biological invasions and complicate attempts to estimate cumulative economic costs from multiple invasive forest species:

- Obtaining necessary data is expensive and time consuming. Reported costs of studies undertaken to assess imports of raw wood into the U.S. range from US$28 000 for a 1992 study of New Zealand wood to US$500 000 for a 1991 study on imports from Siberia (Wallner 2004).
- Estimates of economic losses are usually done for individual invasive species, and involve numerous assumptions, multiple causes of timber losses, different economic approaches, and variations in survey methods and measurements of damage. Differences in methodologies and approaches limit comparability and extrapolation between species and even different years for a given species.
- Timber losses are caused by tree mortality and growth loss. Strict comparison of timber losses between areas affected by major defoliators is not possible, as the extent of growth loss varies with damage intensity, weather conditions, site conditions, tree age and general health. Mortality of a tree due to defoliation depends not only on a succession of defoliation years but also on the type of invasive species, the host tree attacked, site quality, and other environmental disturbances in the region.
- In addition, the impacts of simultaneous attacks of different invasive species may overlap, resulting in overestimates of total timber losses and economic impacts obtained by summing up losses for each species. On the other hand, simultaneous attacks of several invasive species may weaken the trees and compound the rate of growth loss and mortality, which could result in underestimates of total losses (USDA FS 1991).

All costs must be taken into account to obtain objective estimates of the economic consequences of invasion by alien species. Alien invasive forest pests cause losses to natural, commercial and urban forests, but the two main categories of economic impacts that are documented are losses in timber production, and costs of combating invasions, including all forms of quarantine, control, eradication, and tree replacement. Available information on economic impacts usually deals with one or the other; these data alone understate the total economic cost of a biological invasion. Economic impacts of alien species may arise from resources and services with clear market values and from those with non-market values. Again, effects may be direct or indirect (Colautti et al. 2006; Kremar-Nozic et al. 2000a).

Economic losses related to market value of resources and services include those directly inflicted by invasive alien species, timber losses due to tree mortality and reduced growth, and revenue lost from trade, recreation and tourism reductions due to pest infestation. Market-value–related economic losses that are indirectly caused by invasive species include reduced property and aesthetic values.

Impacts to resources and services with non-market values due to invasions of alien species include loss of wildlife and fish habitat, changes in water yield and quality, and lost or reduced biodiversity of forest ecosystems (Gottschalk 1990).

There are also direct regulatory and control expenses, including:

- expenses for research and risk assessment of potentially damaging alien species;
- costs of monitoring, eradication and suppression of infestations once a pest has been introduced, and
- cost of replacing killed or damaged trees.

Economic impact assessment cases

This section presents aggregate-cost estimates of impacts of invasive alien species to forestry in the U.S., Canada, Germany and New Zealand. The cost estimates for each country were obtained using different techniques and assumptions: assumptions for some analyses were reported; results of other studies were obtained from secondary sources, and assumptions were missing. Despite growing interest among policy makers, the public, media and even the scientific community to operate with estimates of cumulative economic losses, direct comparison of the results and summation of the figures presented here are not recommended. None of the impact-assessment studies reviewed includes indirect costs, although the need for such evaluation is recognized (Perrings et al. 2002).

International trade of raw wood is considered a major pathway of introduction for alien species that threaten the importing country's forest ecosystems. Several studies have demonstrated huge potential impacts to the U.S. (Case 2.4; USDA FS 1991, 1998).

CASE 2.4 Projected economic impacts in the U.S. due to import of logs from the Soviet Union

The risk assessment study associated with imports of larch logs from Siberia examined potential financial impacts to commercial forests in the western U.S. These impacts were estimated using cost–benefit analysis and forest sector market models. Major components of potential losses due to five groups of insects and pathogens—nematodes, larch canker, annosus root disease, defoliators and spruce bark beetle—included reduced forest growth, premature harvest, and tree mortality. Potential impacts due to timber losses were estimated to range from US$35 050 million to US$58 410 million for insect defoliators, from US$33 350 million to US$1 670 million for nematodes, from US$201 million to US$1 500 million for spruce bark beetle, from US$84.2 million to US$343.9 million for annosus root disease, and from US$24.9 million to US$240.6 million for larch canker. All estimates were for the 1990–2040 period at a 4% discount rate.

Additional direct costs associated with the control of potential invasive alien species were not considered in this study, nor were related impacts such as reduced recreation and tourism revenues, losses due to reduced national and international reputation, aesthetics and property values.

Source: USDA FS 1991; Krcmar-Nozic et al. 2000a

To quantify the effects of invasive alien species in Canada, Colautti et al. (2006) identified a range of economic impacts in several sectors (Case 2.5):

CASE 2.5 Projected economic impacts to forestry in Canada

In the absence of comprehensive data on the economic impacts of invasive alien species to the forest sector and forest ecosystems, an empirical model was developed to estimate costs.

The potential economic impacts to Canada's forest sector from selected alien organisms were projected. Several impacts of the seven selected alien species—Asian longhorn beetle, balsam woolly adelgid, brown spruce longhorn beetle, Dutch elm disease, gypsy moth, scleroderris canker and white pine blister rust—were considered. These impacts included domestic sales and exports of timber, Christmas trees, maple, pulp and other products.

Given the high value of Canada's forest industry, projected economic impacts in forestry ranged from CAD$7.7 billion to CAD$20.1 billion annually. Increasing global trade is expected to increase opportunities for introduction of new invasive alien species and augment consequent damages to forest ecosystems and the forest industry.

In 2004, the Canadian Food Inspection Agency classified 94 alien species as agricultural or forest pests to be regulated in Canada and estimated an annual cost of CAD$7.5 billion to the Canadian economy by these regulated species. That figure does not include ecological costs to ecosystems by regulated alien species or the impacts of unregulated alien species.

Source: Colautti et al. 2006; BC Ministry of Environment 2004

The major problem with these impact estimates to Canada's forest sector is that the cost projections are based on damage histories of invasive alien species in sectors other than forestry. In addition, the estimates are highly dependent on the loss rates used. On the other hand, the projected costs underscore the economic severity associated with reduced production of natural resources.

National impact assessments created for Germany and New Zealand demonstrate assessment frameworks that could result in more reliable impact estimates (Case 2.6 and 2.7).

CASE 2.6 Incurred and projected economic impacts to forestry and communities in Germany by invasive alien species

The annual costs incurred from alien invaders to forestry and communities in Germany presented here were current costs at the time the study was undertaken. The costs are divided into three categories: direct economic harm, ecological damage that required protection of endangered species and ecosystems, and costs for control measures.

Impacts to commercial forests and conservation areas

The major economic impacts to forests in Germany are due to invasive alien trees. Since the mid-nineteenth century, about 110 alien tree species were imported to Germany for commercial reasons. Several of the introduced tree species, including black cherry (Case 1.5), have disrupted forest ecosystems and the forest industry, and caused negative economic and ecological impacts.

In 2003, the area of black cherry infestation in Germany totaled about 228 km^2, 88% of which were used for commercial forestry, and 11% of which were in conservation areas. About 10,000 km^2 of the country were estimated to be suitable habitat for black cherry and were used as the worst-case scenario in the cost projections.

Black cherry increases forest management costs by prolonging regular forestry practices. Given the current black cherry infestation in Germany and a projected worst-case infestation, additional management costs of €1.4 million and €70 million per year were estimated, respectively.

Eradication efforts are underway in conservation areas, costing €3.4 million annually, whereas €149 million was projected as the cost of eradication within potentially infested conservation areas. For currently infested commercial forests, annual estimated control costs are €20.1 million; projected costs for potentially infested areas of commercial forests across Germany would run to more than €1 billion annually.

Another option considered was no control. Losses to industry deriving from areas colonized by black cherry would be reflected in lost revenues from fir trees, in addition to the adversely affected forest aesthetic value. The study estimated this management option could lead to losses of up to €1.2 billion annually.

The benefits of black cherry harvest are not included in this analysis.

Impacts to urban forests

Most damage to urban forests in Germany are caused by two alien species: chestnut leaf-miner moth (*Cameraria ohridella*) and Dutch elm disease.

Chestnut leaf-miner moth originated in North America and first appeared in Germany in 1993. The primary hosts of this invasive insect are chestnut trees. No cases of chestnut leaf-miner moths causing tree mortality were reported, but the aesthetic value of the tree is adversely affected by infestation, and infested trees become susceptible to other parasites. To contain infestations of the moth, chemical and biological agents have been employed, and leaf litter has been burned in the autumn to reduce infestations in the subsequent year. Horse chestnuts play no role in forestry, but they are among the most common trees in German cities, with an estimated 1 400 345 trees growing throughout the country. Additional litter removal undertaken because of chestnut leaf-miner moth in the five cities investigated added annual costs of €450 000. This yields to total annual costs of €8 million in Germany.

Attempts to control leaf-miner moth infestations have been undertaken only in a few large cities and on a small scale. Municipalities spend €7.66 per tree per year for fertilization as a recommended prophylactic measure to prevent infestation. This procedure would cost around €11.2 million annually if applied to all chestnut trees in Germany. The total incurred costs of litter removal and fertilization are approximately €19.2 million annually in Germany.

If chestnut trees in the city parks and streets eventually die, replacement costs would run to an estimated €10.7 billion, assuming 1.4 million chestnut trees in Germany and a monetary value of €7 700 for a 30-year-old urban tree. Because horse chestnut trees are not native to Germany, there are no obvious ecological consequences of this pest.

Dutch elm disease, native to East Asia, arrived in Europe at the beginning of the 20th century. During the 1960s, incidence of the disease declined, but a more virulent strain was imported with wood products from Canada. Of about 16 000 elm trees in German cities, 412 of these now die each year and must be removed as part of a disease-containment policy. Removal and replacement of a tree costs €4 200, but the value of an established city tree is priced as high as €7 700 per tree. Costs of €1.7 million per year are incurred for tree removal and replanting. The total lost value of established tress is estimated to be equivalent to €3.2 million per year.

Communities in Germany experience direct annual losses of €24.2 million from these two invasive alien species.

Source: Reinhardt et al. 2003

CASE 2.7 Incurred and projected economic impacts of invasive alien species to New Zealand forestry

The New Zealand forest industry is based on highly productive plantation forests and is an important contributor to the national economy. There were 1.83 million hectares of plantation forests in 2003, 89% of which were planted with Radiata pine. Invasive alien species are a significant threat to New Zealand's forests, and to its plantation forests in particular.

Economic impact of insects and pathogens

Turner et al. (2004) estimated the economic costs of invasive alien insects and pathogens to New Zealand's commercial forestry and urban forests. These costs were calculated as the sum of the costs associated with eradication and control programs to reduce forest yield losses, reduced value of harvest due to yield declines, household expenditure to control the alien invaders, and replacement of affected trees in the urban forests. Estimates of annual expected losses to forestry and communities due to invasions of alien insects and pathogens between 2000 and 2040 were discounted to 2000. The estimated net present losses in commercial forestry and urban forests range from NZ$3.75 billion to NZ$20.273 billion, depending on the discount rate (12% and 6%, respectively). For a 10% discount rate, losses are NZ$6.228 billion. The economic impacts of alien invaders on natural forests were not included in these estimates.

Economic impact of weeds

Gorse (*Ulex europaeus*) and Scotch broom (*Cytisus scoparius*) are the two most significant alien woody weeds in New Zealand. The best cost data of weed management in New Zealand have been produced by the forest plantation industry. The costs of clearing gorse, a major weed in plantations, are incurred during site preparation and during the first few years after planting. These costs were NZ$13.1 million in the 1980s. The cost to forestry for weed control in post-harvest site preparation and over the following two years is in the order of NZ$6.00 million annually; this does not include the initial costs of clearing the land of weeds during site preparation. These costs are substantial; the largest company in the country spent NZ$8 million on all aspects of weed control in 1999.

Scotch broom infests a wide range of land and presents a problem on approximately 1% of New Zealand's land area. The economic impacts of broom to New Zealand forestry are not directly available; however, 17 major forestry companies, which managed a total of 1.6 million hectares, spent NZ$1.3 million in 1999 on controlling broom. Broom has a particularly severe impact on production volumes in the 8 000 hectares of dry production forests in the eastern part of the South Island. If broom causes a productivity loss similar to that of gorse—i.e., a loss of 2% of production—then the annual production loss, net of harvesting and freight costs is NZ$600 000. These estimates show that even when weed species such as gorse and broom have only slightly different ecologies and control regimes, their costs to forestry industry are additive.

Broom is also widespread on conservation land. Because of the enormous cost of control, it is controlled only on high-value sites. In 1999, New Zealand Department of Conservation and other Crown agencies spent NZ$500 000 and NZ$700 000, respectively, to control broom on land under their control.

Source: Turner et al. 2004; Williams and Timmins 2002

3. Introduction and establishment of invasive alien species

This chapter focuses on the introduction and establishment of alien species in new habitats; these two stages distinguish alien species from native forest pathogens and pests.

Pathways for the introduction of alien species

Modes of introduction of alien species are grouped into three categories: deliberate, accidental and natural. Many plant species have been introduced deliberately either through importation or smuggling. On the other hand, most insect and pathogen introductions have been accidental, often attached to other species (plants and animals). Species can also be introduced naturally by wind, water or debris; however, an insignificant number of invasive alien organisms are introduced that way. Both deliberate and accidental introductions of alien species could and should be prevented; no means to stop natural entry of alien species exists.

Trade, transport and travel

Both deliberate and accidental introductions of alien organisms are associated with legitimate trade, transport and travel (Starfinger et al. 2003). When people settle in new territories, they sometimes try to make the new environment more familiar by importing popular plant species from their native land. If these plants become invasive, they can threaten biodiversity in the new environment. They can also be vectors for insects and pathogens, which in turn may cause economic and environmental damage in the area, region or country where they are introduced.

Trade in nursery stock of any kind is an important pathway for accidental introductions of alien species. Imports of the miniature bonsai plants from Asia—mainly Japan and China—have facilitated introductions of invasive alien species to Europe and North America. In 1973, three species of Japanese aphids were introduced to Britain on imported bonsai trees. Establishment and dispersal of these species were highly probable because suitable host trees planted as ornamentals were abundant in Britain (Prior 1974). The species *Rhizoecus hibisci* was found on the roots of bonsai plants imported from Japan into Italy (EPPO 2005). In 2004, the citrus longhorned beetle (*Anoplophora chinensis*) was discovered at a nursery in Athens, Georgia, on myrtle bonsai imported from China. The citrus longhorned beetle is similar to Asian longhorned beetle (*Anoplophora glabripennis*), but from Florida's perspective may be a greater threat: it attacks many hardwood trees species—including citrus, but also pecan, apple, Australian pine and many others (Thomas 2004).

Bonsai trees are not the only plants that are associated with the introduction of unwanted pests and pathogens: in 2003, sudden oak death (*Phytophthora ramorum*) disease was found at a nursery in California. Several rhododendron and camellia plants from that nursery had been imported by garden centres to the lower mainland of British Columbia (Case 4.2).

Major forestry pathways

The transport of forest material and wood products is a major pathway for introduction of alien species that may invade forest ecosystems and harm the forestry sector. The Asian longhorn beetle, pine shoot beetle, chestnut blight and Dutch elm disease are examples of species imported into North America by this pathway.

Trade in untreated (also called raw, green or unmanufactured) wood products is a particularly high-risk pathway for introduction of forest insects and pathogens into new environments (Tkacz 2002). Untreated wood products include raw logs, poles, lumber and all other wood products that have not been treated for pest eradication (see Chapter 4 for treatment options). When these products are shipped in

containers, the risk of introduction increases, as the container provides protection during transportation to species associated with the wood and limits access for inspection.

Packaging materials used in the shipment of internationally traded goods is frequently composed of low-quality wood. Wood packaging products include dunnage, crating, pallets and other products made of untreated wood. This packaging represents a significant pathway for introduction of alien organisms inhabiting wood (CFIA 2004; Cock 2003; Case 3.1).

CASE 3.1 Introductions of alien species in Canada associated with solid wood packing material

In 1997, Canadian Forest Service scientists examined wooden spools carrying wire from China. Live wood-boring beetles were found in 24% of the 50 spools examined, and tunnels indicating internal woodborer activity were found in 31% of the spools. In the subsequent year, more than 40 species of beetles and associated parasitoids were found in green wood bolts used as dunnage in the shipment of granite blocks from Norway.

Source: Allen 2001

Some alien species can be introduced in association with forestry practices, either accidentally or deliberately. These pathways may be through silvicultural practices, movement of germplasm or contaminants of fruit and seed (Cock 2003). Twenty out of twenty-three alien insect species that have become established in California since 1980 arrived on plants imported for commercial forestry (OTA 1993). Insects and pathogens may be hidden in conifer cones, nuts and fruits of forest trees. An example of a pest that likely was imported via this pathway is the Douglas-fir seed chalcid, *Megastigmus spermotrophus*, which was introduced to Europe from North America and has subsequently become Europe's most important pest of conifer seed orchards (Roques 2001). One of the pathways identified for introduction of butternut canker into new environments is the transportation of contaminated nuts by people (Case 2.3).

International trade

Lower transportation costs and greater trade liberalization and globalization during the last decade have lead to an expansion in world trade. Table 3.1 lists the world's most active trading countries and regions in 2004.

Table 3.1 Share in world total trade in 2004

	Share in world total (%)	
Country	Imports	Exports
EU(25)[1,2]	18.3	18.1
USA	16.0	8.9
China	5.9	6.5
Japan	4.8	6.2
Canada	2.9	3.4

[1]EU (25) refers to the members of European Union (EU) as of May 2004.
[2]For the EU (25) as one trading partner, the share is calculated on the basis of world trade excluding intra-EU (25) trade.

Source: WTO 2006

In 2004, the European Union was the world's leader in trade (in terms of both exports and imports), and Canada ranked fifth. However, the U.S. is the world's top trader if the individual country's share in world total trade is calculated by taking internal trade within the European Union into consideration. U.S. imports greatly exceed those of any other country and are more than five times those of Canada.

Globalization of trade has greatly increased the number of alien species introduced into new habitats. For example, U.S. trade with China has risen exponentially in recent years. The number of insects found in materials imported from China has increased, too—from 1% of all interceptions in 1987 to 20% in 1996 (Berenbaum 2001).

Canadian trade

Introductions of alien species into Canada are becoming more frequent and difficult to track as global trade and travel expand. Europe used to be an important origin of alien species introduced into Canada, but recently more species have been arriving from Asia (Case 3.1; Case 3.2). More frequent travel between regions within Canada is also speeding up the spread of alien species to remote areas within the country (Canadian Wildlife Service 2003).

The U.S. has been and continues to be the main source of invasive alien species introduced to Canada. The reasons for this are: a huge volume of the U.S. trade relative to the rest of the world (see Table 3.1); high volume of Canadian imports from the U.S.; openness of the borders for business and tourist travel, and; similar environmental conditions in Canada and the U.S. (Perrault et al. 2003).

Canada's trade patterns and trends may help explain a significant factor in the current explosion of introductions of alien invaders into new habitats. Table 3.2 presents Canada's main trading partners for 2004: values of trade across all industries and percentage shares are presented for the leading five trading partners.

Almost 60% of all Canadian imports come from the U.S.—five times the amount of imports into Canada from the European Union. Imports from China are increasing.

The U.S. also imports the most Canadian goods, opening a pathway for introduction of invasive species from Canada to the U.S.

In terms of Canada's trade of forest products, the situation differs slightly. The differences occur with some of the trading partners as well as in the trade shares. Table 3.3 presents Canada's major partners in trade of forest products. Both the values of trade across all forest products and the percentage shares are presented for the leading five trading partners.

About 80% of Canadian imports of forest products come from the U.S. Eight times the amount of forest products are imported from the U.S. compared to from the European Union. This high volume of forest imports from a single country makes this trade partnership one of the major pathways of alien forest pests and pathogens into Canada.

Table 3.2 Share in Canada's total trade in 2004

Imports			Exports		
Country	Value (mil. CAD$)	Share (%)	Country	Value (mil. CAD$)	Share (%)
U.S.	208 971	58.7	U.S.	348 142	84.5
European Union	42 001	11.8	European Union	22 833	5.5
China	24 100	6.8	Japan	8 558	2.1
Japan	13 511	3.8	China	6 655	1.6
Mexico	13 434	3.8	Mexico	2 995	0.7

Source: Industry Canada 2006

Table 3.3 Share in Canada's trade of forest products in 2004

Imports			Exports		
Country	Value (mil. CAD$)	Share (%)	Country	Value (mil. CAD$)	Share (%)
U.S.	7 657	78.3	U.S.	35 293	79.4
European Union	953	9.7	European Union	2 552	5.7
China	433	4.4	Japan	2 432	5.5
Brazil	160	1.6	China	1 127	2.5
Indonesia	76	0.8	South Korea	538	1.2

Source: Industry Canada 2006

Establishment of alien invaders

Establishment of most alien species in the past few decades has taken place near airports or seaports (Case 3.2; Case 4.2).

CASE 3.2 Establishment of wood-boring beetles in British Columbia

The Canadian Forest Service initiated a study in 1995 to determine the establishment of alien bark and wood-boring beetles in forests in the greater Vancouver area. The beetle-trapping program was conducted in two protected forested areas near the Vancouver International Airport: the Richmond Nature Park, an 80-hectare urban forest, and the Alaksen National Wildlife Area, a 300-hectare mixed-wood forest. By examining traps from the two sites, six newly introduced alien species of bark or wood-boring beetles were proven established in British Columbia. One of these species originated in the subtropics, two species likely arrived from temperate Europe, two species were native to temperate northeast Asia, and one was introduced from eastern North America.

Source: Humble et al. 1999

With increased use of containers for transport of trade commodities, goods off-loaded at seaports or airports may be moved by truck or railway to anywhere within an importing country. This increases opportunities for alien species to be established far from their ports of entry (Allen and Humble 2002).

After introduction at the point of entry, some species establish themselves and soon undergo an explosive outbreak in population size and range. Establishment rates vary, with some alien species becoming established only after considerable lag times. Reasons for establishment after delay include alteration of the alien species itself, climate change, and human impact in the area of introduction (Cock 2003; Williamson 1996). Species also require different amounts of time to adapt to new habitats. Some species go through a long period of exponential growth and may therefore appear to suddenly increase in population size and become invasive. Loope and Howarth (2003) predicted that, in terms of status of invasive alien species over the subsequent five years, "because of the lag time in invasions, we will be dealing largely with alien species currently present but not yet recognized as problematic."

4. Management strategies

There are four components to strategies that deal with alien species: prevention, or exclusion, of introductions, early detection, eradication, and control (Wittenberg and Cock 2001). These components relate directly to the four stages of a biological invasion identified in Chapter 1. Table 4.1 lists the stages of biological invasion and their related management strategy components; Figure 4.1 illustrates the relationships.

Table 4.1 Invasion stages and related management strategy components

Invasion of alien species	*Management components*
Introduction	Prevention
Establishment	Early detection
Integration	Eradication
Spread	Control

Trends in managing species that damage forests are moving towards more sustainable management strategies because of changing perceptions of the role of forests. One example is a great decline in pesticide use by forest industries in developed countries. Within the sustainable management paradigm, prevention of biological invasions is preferred to control of established invasive species. Although prevention is insufficient for keeping alien organisms out of a country, it may allow for more effective eradication and avoidance of longer and costly control programs. The scientific community argues that preventing introductions is the first and most cost-effective line of defense against invasive alien species (Perrings 2005; Wittenberg and Cock 2001; Cambell 2001): in addition to the high cost of eradication and control treatments in forestry, application of many control measures is controversial from the public perspective (Wallner 2004). Preventing introductions is, therefore, the preferred strategy against invasive alien species in forestry. However, national policies vary worldwide because of the high costs of prevention and concerns about potential disruptions of trade.

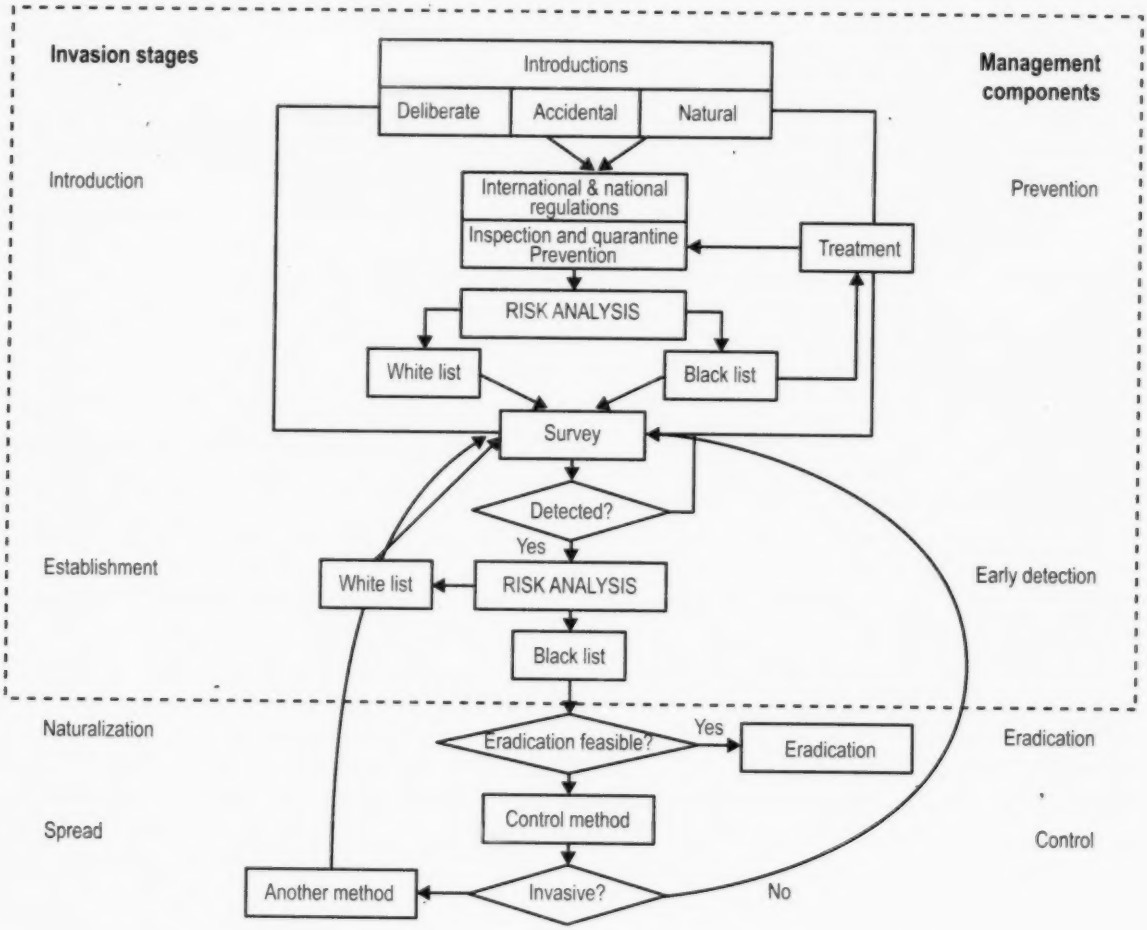


Figure 4.1 Summary of the components of management strategies vis-a-vis various stages of invasions by alien species (modified after Wittenberg and Cock 2001).

Consistent with the approach undertaken in Chapter 3 to address only the introduction and establishment of alien species, this chapter focuses on prevention and early detection options for addressing invasive alien species.

The steps in the boxed part of the flowchart in Figure 4.1 illustrate a recommended framework for preventing introduction and establishment of invasive alien organisms into a country. Under international and national regulations regarding introduction of invasive species, deliberate introduction of (plant) species and commodities is subject to pest risk analysis. Accidental introduction of invasive species associated with certain commodities and pathways may be prevented by conducting risk analyses of the proposed imported commodities and known pathways. Risk analyses results are used to recommend or ban import of certain commodities into a country; they are also used to produce two lists: "black" or "dirty" lists of species known to be harmful somewhere and therefore banned from entering the country, and "white" or "clean" lists of species with no known history of causing damages and, thus, permitted entry. Current practice in most countries (excluding Australia and New Zealand) for dealing with alien invaders recognize species as problematic and black list a species only after it has caused problems either in the country of origin or elsewhere. In the U.S., for example, adding species to this list can take years, particularly if this action conflicts with the economic interests of groups or sectors with political or economic influence (Berenbaum 2001).

Despite measures undertaken to prevent introduction of invasive species, some invasive organisms continue to enter countries by being either smuggled or missed by border inspections. Surveys should be conducted to detect and monitor both alien species not detected by pre-border or border inspection and species from the white list that are given a green light to enter the country, and whether either causes damage in that country.

Preventing introductions by interception

Prevention of alien species introductions is managed through enforcement of regulations, preferably employing inspections and fees. Both accidental and deliberate introductions through trade are best addressed before goods and their associated organisms are exported from the country of origin or upon arrival of goods at the port of entry into the importing country. Responsibility for preventing introduction of alien species usually rests with national government administration. It requires border inspection and exclusion programs. After appropriate inspection has been carried out, a phytosanitary or sanitary certificate can be issued. In addition to border inspection, post-entry inspection of plants and animals can be used to check for presence of alien species associated with the imported goods. Thus, inspection can be conducted at the (1) pre-border, (2) border, and (3) post-border level.

Systems of regulations and inspections have been established in most developed countries to safeguard against pest introduction. Regional and global trade by North American countries has grown significantly, but capacity for inspection for alien species has remained at approximately 2% of commodities being inspected. For example, in 2004, U.S. and Canadian imports accounted for US$1.525 trillion and US$279 billion, respectively (WTO 2006). The potential for unnoticed introduction of invasive alien species via trade has increased significantly (Perrault et al. 2003).

In 1951, 79 nations adopted the International Plant Protection Convention (IPPC; https://www.ippc.int/IPP/En/default.jsp; accessed July 17, 2006) to prevent the spread of dangerous plants, insects and diseases. The IPPC advances several principles, one of which is the process of pest risk analysis (FAO 2004). The risk analysis includes assessment of the probability of introduction and spread of a species considered a quarantine pest, and potential economic and ecological consequences. Although most of the IPPC principles and mechanisms are of great importance, in practice the recommended process of pest risk analysis is not easily applied to forestry (Wallner 2004). Because forest ecosystems are highly complex, and the invasive capacity of most alien species is not thoroughly understood, their potential

impacts and degree of harm are not easily predicted. This type of analysis for forests is very important at the pre-border or border stage, but is not always effective due to lack of information.

Risk Analysis

Risk analysis includes four main steps: initiation of the risk analysis, risk assessment, risk management and risk communication (FAO 2004; Cock 2003). Although researchers may classify the steps of risk analysis differently, the content of each risk analysis is more or less consistent.

Initiation: A risk analysis can be initiated by the identification either of a pathway allowing the introduction of an alien species that may qualify as a quarantine pest, or of a species that may qualify as a quarantine pest. Details about the initiation process are provided in FAO (2004).

Before initiating a risk analysis, it is necessary to check whether the pathway or species has already been analyzed nationally or internationally. If it has, this would provide an initial point of reference; however, the species or pathway should be re-evaluated because of different, changing or more current circumstances.

Risk assessment determines likelihood of a suspected species or a species associated with a pathway to be successfully introduced, become established and become invasive. A risk assessment also estimates the species' potential ecological and economic impacts. A species is assessed by reviewing relevant literature, through expert opinions, and qualitative and quantitative analyses.

The results of these two components—likelihood of invasion and potential impact—are usually ranked along a simple qualitative rating scale of "high," "medium" or "low" risk, or according to a numeric score. The final risk assessment's qualitative rating is obtained by multiplying the previous two results. For example, a species with low likelihood of introduction or establishment, but very high potential impacts might still receive an overall risk assessment of "high."

Risk assessment can be used to support the exclusion of certain species from trade before their import into the area, or it can be applied after the species is established to assess the risks of its invasiveness. When risk assessment is conducted for an already-established alien species, various models may be applied to estimate potential ecological and economic consequences.

At the end of the risk assessment, individual species or those associated with a pathway are placed on either a black or white list, depending on the risk potential for invasion and damage. Outcomes of risk assessment are used to help determine whether management actions should be taken, and, if so, what actions. Risk assessment is also used to set priorities for allocation of limited time and funds. Combined with risk communication, the risk assessment process and outcomes are used to obtain public support and funding for exclusion or eradication.

Risk communication is the communication of risk assessment results to policy makers, to the public, and to managers so that the results are clearly understood and rational decisions can be made. The public must support management decisions and actions; its understanding, acceptance and support are essential for effective action against alien species.

Risk management deals with actions undertaken with regard to species identified as risks to the environment and economy (i.e., black-listed species). It includes setting objectives, weighing management alternatives, assessing consequences and acceptable levels of risk, and prioritizing trade-offs. In doing so, risk assessment outcomes are linked to available options, and risk management becomes a key step in a decision-support framework to select plans of actions from among available management alternatives.

Management activities at the introduction stage

If imported goods or their packing materials are suspected to contain alien organisms, implementation of treatment technologies that may involve fumigation and pesticide application, water immersion, heat and cold treatment, or irradiation may be necessary.

Fumigation is frequently used to kill insect infestations in fruits, vegetables and timber. These commodities are treated with gas at specific atmospheric pressures and temperatures for specific time periods, depending on the commodity and the suspected pest. Methyl bromide has been the most commonly used chemical, but is increasingly being phased out; alternatives are being sought. Other chemical treatment protocols entail fluids and dipping procedures.

Temperature treatments apply cold or hot temperatures to eradicate alien species. Commodities are either refrigerated at a specific temperature for a specific number of days or dipped into hot water at a specific temperature for a specific period of time.

Ultra Violet Light (UVL) sterilization is a viable and environmentally benign approach to treat commodities. High-intensity UVL irradiation is particularly effective for small organisms.
Treatment combinations: When the efficacy of a single method is not satisfactory, and the risk of introduction of alien organisms exceeds acceptable levels, a combination of different treatment methods is often necessary. This occurs in a significant number of cases.

Embargoes: When strict measures do not prevent introductions of potentially harmful species, an embargo can be put in place. The embargo, or trade prohibition based on international regulations, can be applied to particular products, source regions, or routes. Under the World Trade Organization's Sanitary and Phytosanitary (WTO-SPS) Agreement, member countries have the right to take sanitary and phytosanitary measures necessary to protect human, animal and plant life or health, provided these measures are based on scientific principles (WTO-SPS http://www.wto.org/English/tratop_e/sps_e/sps_e.htm; Case 4.1).

CASE 4.1 Embargoes on the import of forest products from North America

In 1984, Finnish plant inspection authorities found pinewood nematodes (*Bursaphelenchus xylophilus*) in pine chips imported from the U.S. and Canada. As a result, Finland banned import of chips and lumber cut from coniferous trees grown in the areas with occurrences of pinewood nematode. In 1985, the European and Mediterranean Plant Protection Organization recommended that European countries ban all coniferous products except kiln-dried lumber from the U.S. and Canada, because of pinewood nematode. The North American forest sector has suffered significant economic losses due to the embargo.

In 1990, Finnish plant inspection intercepted live nematodes in wood packaging used for shipping onions from Canada. Despite a requirement, adopted by Finland in 2000, that phytosanitary certificates must accompany shipments containing coniferous wood packaging, a steady introduction of pinewood nematodes into the country has continued.

Source: Allen and Humble 2002; Tomminen 2000; Dwinell and Nickle 1989

Management activities at the early detection stage

Early detection is essential to prevent establishment and spread of invasive alien organisms. New introductions are often discovered too late to be eradicated. According to Williamson (1996), roughly 10% of introduced species will become established, and about 10% of those will become invasive and become economic and environmental threats. Early detection of alien species is primarily based on a system of regular surveys to find newly established species.

Surveys are undertaken to detect new invasive species at an early stage of biological invasion. Some invasive species are easily detected, whereas others require special efforts to locate or identify them, particularly when they are low in numbers. Surveys are not necessarily intended to gather scientific data, but can be designed for the general public to assist with. Surveys are most effective when they target species known to be invasive under similar conditions in other regions or countries.

Three types of surveys may be considered: general, site specific and species specific. Depending on the purpose, these categories may merge or overlap. Staff responsible for implementing the surveys must be trained either in-country or by taking courses held abroad. Furthermore, especially at sites of high conservation value and at high-risk entry points near habitats of endangered species, surveys must extend beyond specific species or commodities to deal with common pathways for a wide variety of alien organisms (Case 4.2).

CASE 4.2 Early detection of the brown spruce longhorn beetle in Nova Scotia

The brown spruce longhorn beetle (*Tetropium fuscum*) is considered a secondary pest of European spruce forests. In 1999, this beetle was discovered in Halifax on dead and dying red spruce. In early 2000, the beetle was identified by Canadian Forest Service researchers as a cause of mortality of healthy red spruce in the Halifax Regional Municipality. This was the first known interception of this invasive forest pest in North America. It is believed that this pest arrived in Canada in solid wood packing material via the port of Halifax.

The staff of the Canadian Food Inspection Agency and Nova Scotia Department of Natural Resources conducted ground surveys in Halifax to determine the beetle's distribution. In addition to the Nova Scotia program, a national survey was conducted in the fall and winter of 2001, at ports and dunnage disposal and storage areas. Thousands of trees have been examined across Canada, but presence of the beetle has not been reported outside of Nova Scotia.

Source: CFIA 2003; Smith and Hurley 2000

Public education is another important measure for early detection. Education programs may target groups already acquainted with the natural environment and extend into media promotion. Travelers are often unaware of laws and regulations to prevent the introduction of alien species and the reasons for them. Education programs should focus on raising awareness of the rationale for the restrictions. For example, the British Columbia Ministry of Forests and Range has developed a database for invasive plants in British Columbia, which is intended to share information generated by various agencies and non-government organizations involved in invasive plant management (http://www.for.gov.bc.ca/hfp/invasive/; Accessed October 16, 2006).

Databases: Another high-priority measure that would assist in detection of alien species at an early stage of invasion involves availability of records of species identified through the surveys. Databases should be established on alien species encountered in border inspections, including information on places of origin and pathways involved. If such databases were available to other countries, prevention measures could be made more effective on a global scale. Although databases of species known for their invasiveness are available from many organizations, they are scattered around the world, present various classification systems and are enabled by different search tools. An example of a broad-scope database is BioNET International, a global network for capacity building in taxonomy (BioNET 1999).

There is a deficiency in databases specialized in alien forest pests and pathogens. Case 4.3 examines one of the few.

CASE 4.3 ExFor database of alien species causing damage to forest resources

ExFor is a North American database that compiles information about alien organisms with potential to cause significant damage to forest resources in Canada, the U.S. and Mexico. ExFor is a joint project of the member organizations of the Insect and Disease Study Group of the North American Forest Commission. These organizations include the Canadian Forest Service, the Canadian Food Inspection Agency, Mexico's Sanidad Forestal, the U.S. Department of Agriculture Forest Service, and the U.S. Department of Agriculture's Animal and Plant Health Inspection Service.

Source: ExFor 2006

In order to create black lists of invasive species, databases need to collect detailed data about native forest pests and pathogens. For example, a recently published book describing 175 species of forest defoliators in British Columbia, Canada, could serve as an excellent source of information about potentially black-listed insects when risk analysis is initiated (Duncan 2006).

We have discussed here only activities related to introduction and early detection of invasive alien species. Once a species is established, the eradication and control steps are generally similar to those undertaken with native pests and diseases.

5. Policies and institutions

This chapter reviews the most important international, and some of the regional and national, policies, agreements and institutions used to prevent and regulate invasive alien species in the context of forest ecosystems. In 2003, there were about 20 multilateral agreements regarding alien species at either the global or regional level (Kreith and Golino 2003).

International organizations and agreements

International agreements relevant to regulating invasive alien species form a basis for Canadian policy and institutions addressing invasive alien forest species.

The Convention on Biological Diversity (CBD), the first major global agreement on the conservation of biodiversity, was signed in 1992 at the Rio de Janeiro Earth Summit (http://www.biodiv.org/default.shtml/; accessed July 10, 2006). The CBD provides general guidelines to signatory members to address the issues of alien species by recommending "each Contracting Party shall, as far as possible and appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species" (CBD, Article 8(h); http://www.cbd.int/convention/convention.shtml; accessed July 10, 2006).

The International Plant Protection Convention for the protection of plants (IPPC; https://www.ippc.int/IPP/En/default.jsp; accessed July 10, 2006), formed in 1952, defines actions for preventing the introduction and spread of plant pests and promoting appropriate measures for their control. The IPPC Secretariat, hosted by the United Nations Food and Agriculture Organization (FAO), prepares the international standards for phytosanitary measures (ISPMs). The ISPMs and the guidelines to achieve international harmonization of phytosanitary measures are available to FAO members and other interested parties. The aim of these standards is to facilitate trade in plants and plant products and to avoid use of unjustifiable measures as barriers to trade.

The World Trade Organization (WTO; http://www.wto.org/; accessed July 10, 2006) Sanitary and Phytosanitary (SPS) Agreement was created during the Uruguay round of negotiations (1986–1994). The SPS agreement attempts to balance members' prerogatives to protect themselves from threats that may be introduced through foreign imports with the multilateral goal of eliminating protectionist restrictions. It encourages, but does not require, compliance with international standards. Members are free to choose higher levels of protection, but must justify such measures through sound science (Smith 2003):

> *Members shall ensure that their sanitary and phytosanitary measures do not arbitrarily or unjustifiably discriminate between Members where identical or similar conditions prevail, including between their own territory and that of other Members. Sanitary and phytosanitary measures shall not be applied in a manner which would constitute a disguised restriction on international trade.*
>
> Source: WTO-SPS, Article 2.3, 1995

Furthermore:

> *Members shall ensure that such measures are not more trade-restrictive than required to achieve their appropriate level of sanitary and phytosanitary protection, taking into account technical and economic feasibility.*
>
> Source: WTO-SPS, Article 2.3, 1995

With regards to international trade in plants, the IPPC and the regional plant protection organizations are charged with developing phytosanitary standards that implement WTO-SPS measures.

North American-wide organizations and agreements

The North American Plant Protection Organization (NAPPO) is one of the regional plant protection organizations under the IPPC, and is responsible for developing North American phytosanitary standards. Chapter 7 of the North American Free Trade Agreement (NAFTA) provides guidelines similar to those within the WTO-SPS Agreement; it promotes the use of international standards for controlling plant pests, specifically recognizing the work of the IPPC and NAP.

The North American Forest Commission (NAFC; http://www.fs.fed.us/global/nafc/; accessed July 10, 2006) is a regional forestry commission of the United Nations Food and Agriculture Organization (FAO). NAFC has addressed forest issues on a North American basis since 1958, and has undertaken the Exotic Forest Pest Information System (ExFor) as a joint project of the member organizations of the Insect and Disease working group (Case 4.3).

National institutions and policies

Different strategies regarding invasive alien species have been adopted in different countries, across continents, and even within various sectors and regions of individual countries. The following sections explore the policies and institutional frameworks in Canada, the U.S., European Union, Australia and New Zealand. Major reasons for providing this analysis are the U.S. and European Union are Canada's major trading partners, and Australia and New Zealand have been subjected to many biological invasions and have developed advanced biosecurity systems. Both the information gaps and experience in regulating and managing invasive alien species in these countries may be of interest to Canadian policy makers and forest sector managers.

Canada

The major institutions addressing the introductions of invasive alien species to forestry and ecosystems in Canada are the Canadian Food Inspection Agency, the Canadian Forest Service and Environment Canada.

The Canadian Food Inspection Agency (CFIA; http://www.inspection.gc.ca/; accessed July 10, 2006) develops science-based procedures to prevent the introduction and establishment of alien invaders into Canada. The agency performs surveillance and implements procedures for control of invaders that are already present in the country. The CFIA regulates a number of pest types and performs risk assessment for numerous pathways and organisms. It also provides leadership in the implementation of the Canadian Invasive Alien Species Strategy.

The Canadian Forest Service (CFS; http://www.nrcan.gc.ca/cfs/; accessed July 10, 2006), an agency under Natural Resources Canada, promotes sustainable development of Canada's forests and competitiveness of the Canadian forest sector. The CFS is the principal federal forest research organization in Canada that addresses invasive alien species that may damage forest ecosystems and the forest sector, and provides information on ecological aspects of potential forest pests and on the potentials for their establishment and spread. It also undertakes surveys for detection, identification and monitoring of potential forest pests, and develops systems for prediction, prevention and mitigation of invasions by alien forest pests.

The CFS has been a key participant in the development of Canada's new National Forest Pest Strategy. The strategy, which was approved September 2007, covers both alien and native forests pests, and seeks to coordinate federal, provincial and territorial government efforts in controlling forest pest issues that cross jurisdictional boundaries within the country. The CFS recently used the methodologies outlined in the strategy and based on those recommended by the IPPC's risk assessment ISPM to assess the risk of mountain pine beetle expanding beyond its range in western Canada into the country's boreal forests (Bill Wilson, Canadian Forest Service, Pacific Forestry Centre, Victoria, B.C., personal communication).

Environment Canada is the leading agency on the overall topic of invasive species affecting natural ecosystems in Canada. Environment Canada developed the National Biodiversity Strategy according to the requirements of the CBD (Environment Canada 1994); this strategy includes several elements related to prevention and control of invasive alien species. Environment Canada was also involved in developing a national strategy on the prevention and control of invasive species; the Canadian Invasive Alien Species Strategy was introduced in September 2004 and has four main goals:

(1) prevention of deliberate and accidental introductions;

(2) detection and identification of new invaders;

(3) rapid response with regards to new invaders, and;

(4) efficient management of established invaders (Environment Canada 2004).

The strategy is carried out in cooperation with other federal, and provincial and territorial government agencies, non-government agencies, academic institutions and individual Canadians.

United States

The major institutions in the U.S. that address threats to forestry and forest ecosystems arising from invasive alien species are the National Invasive Species Council, the U.S. Department of Agriculture (USDA) Forest Service, and Animal Plant Health Inspection Service (APHIS).

The National Invasive Species Council (NISC) was established in 1999 and is mandated to

> *...provide national leadership on invasive species; see that their Federal efforts are coordinated and effective; promote action at local, State, tribal and ecosystem levels; identify recommendations for international cooperation; facilitate a coordinated network to document and monitor invasive species; develop a net-based information network; and provide guidance on invasive species for Federal agencies to use in implementing the National Environmental Policy Act.*
>
> Source: Clinton 1999

At the federal level, the USDA Animal Plant Health Inspection Service (APHIS; http://www.aphis.usda.gov/; accessed July 10, 2006) is the main department responsible for implementation of NISC's management plan. USDA APHIS is responsible for conducting inspections and quarantine of commodities coming into the country, conducts research and provides assistance to the private sector in pest control projects. APHIS's Plant Protection and Quarantine department is primarily responsible for the implementation of laws regarding invasive species.

Invasive alien species of forest ecosystems and wildlife habitat are the concern of the USDA Forest Service (http://www.fs.fed.us; accessed July 10, 2006), but they are also regulated and managed by variety of other federal and states agencies. The forest service has identified invasive alien species as one of the four critical threats to the country's forests. Invasive alien species have been characterized as a "catastrophic wildfire in slow motion" (USDA FS 2006a), affecting the health of not only forests and rangelands, but also of wildlife, livestock, fish and humans. The forest service considers an alien species invasive if it meets two criteria: it is not native to the ecosystem under consideration, and its introduction causes or is likely to cause economic or environmental harm, or harm to human health (Clinton 1999).

Components of the forest service's national strategy on invasive alien species are prevention, early detection and rapid response, and control and management (USDA FS 2004). Preventive measures are considered the most cost-effective means of reducing or eliminating environmental and economic impacts of invasive alien species in the U.S. Prevention relies on a diverse set of tools and methods combined with effective domestic and international partnerships (USDA FS 2004).

Forest service programs for early detection, control and management of invasive alien species identify and prioritize invasive species that will be controlled and managed, based on risk assessment, identification of thresholds for action, and planning, to reach the most desired outcome. Control and management activities are founded on integrated pest management principles that include a combination of physical, mechanical, biological, cultural, and chemical techniques. The forest service has developed several tools to support control and management activities of invasive alien species (Case 5.1).

CASE 5.1 Tools to predict geographic distribution of alien invaders in the U.S.

The Forest Health Technology Enterprise Team of the USDA Forest Service's Forest Health Division, created in 1995, has modeled the impacts of several insects and pathogens at the landscape level. The team developed a mapping tool that uses existing data to predict the geographical extent of future damage from beech bark disease, hemlock woolly adelgid and gypsy moth. The distributions of host trees of these alien invaders were mapped in 1-km^2 cells by interpolating forest-inventory data in 37 states. According to report estimates, beech bark disease currently occupies only about 27% of its potential range in land area, but has invaded more than 54% of its total host density. Hemlock woolly adelgid occupies nearly 26% of its potential range in land area, and about one-quarter of its total host density. Gypsy moth occupies only 23% of its potential range in the eastern U.S., and only 26% of total host density.

The Forest Service scientists developed another suite of models to conduct insect and disease risk analysis. One of its latest products is risk mapping for certain invasive species. Figure 5.1 provides a graphical illustration of the potential for introduction and establishment of sirex woodwasp (*Sirex noctilio*) in the U.S.

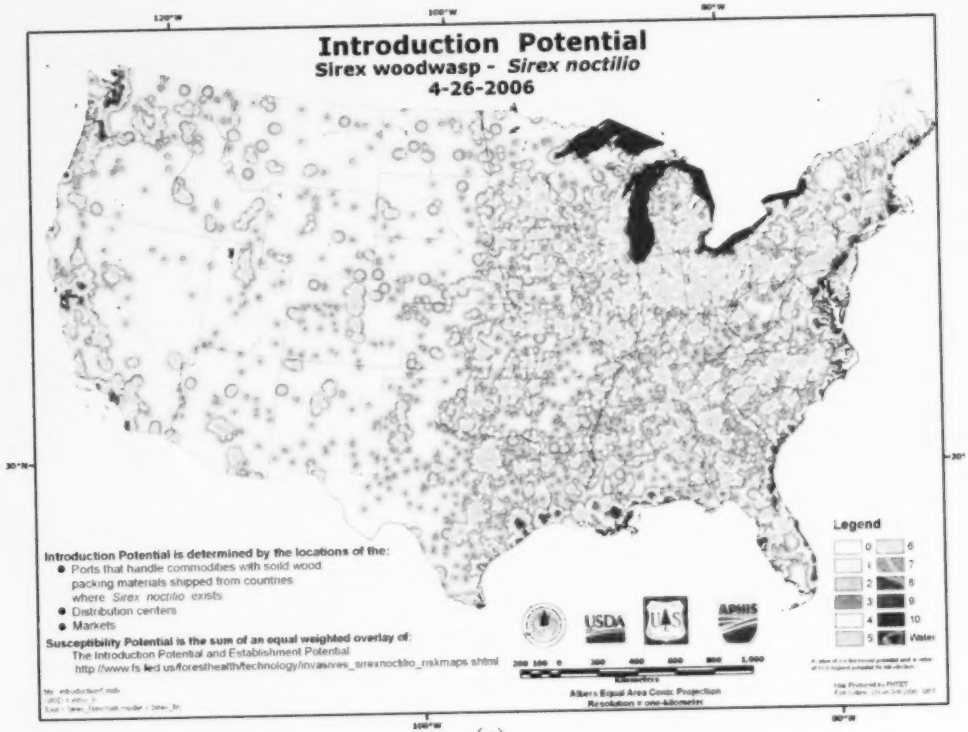
Source: USDA FS 2006b; USDA FS 2006c; Morin et al. 2005

European Union

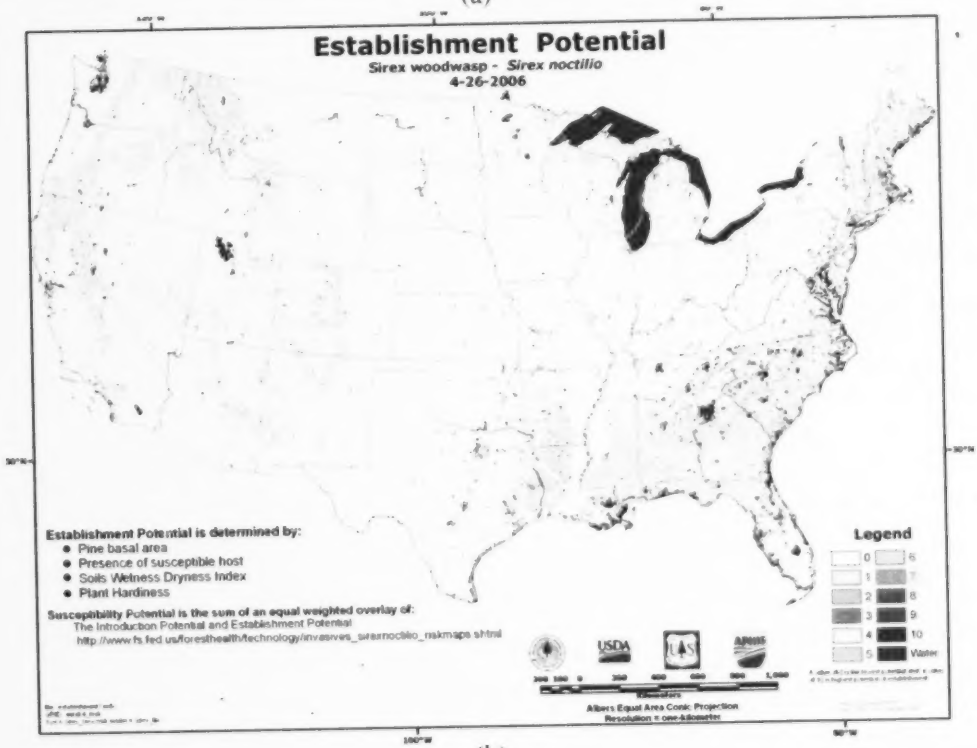
No legislation exists in the European Union (EU) to deal specifically with invasive alien species, even though the EU is a signatory member of more than 40 international and regional agreements containing programs related to invasive alien species (Scalera and Zaghi 2004). Only in recent years have invasive alien species received more attention from the EU.

In 1979, the Convention on the Conservation of European Wildlife and Natural Habitats was signed in Bern. This agreement includes important provisions and recommendations dealing with alien species. To protect endangered wildlife from unsustainable trade, the EU has also adopted a number of laws, generally known as wildlife trade regulations, aimed at implementing the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES; http://www.cites.org/eng/disc/text.shtml; accessed July 10, 2006).

In 1998, the European Commission adopted the Communication on a European Community Biodiversity Strategy, with specific references to invasive alien species. The European biodiversity strategy is implemented through action plans across four sectors: conservation of natural resources; agriculture; fisheries, and; economic and development cooperation (European Commission 1998). Forestry is not considered a specific sector of interest within the strategy but rather a subset of natural resources.



(a)



(b)

Figure 5.1 Potential for (a) introduction and (b) establishment of sirex woodwasp in the U.S. (Source: USDA FS 2006c)

The actions dealing with invasive alien species recommended in the Conservation of Natural Resources Plan include:

- updating the list of invasive alien species known to be ecological threats to native flora and fauna, habitats and ecosystems within the EU;
- promoting exchange of information regarding existing legislation, guidelines and experience, including measures to control or eradicate invasive alien species, or prevent their introduction, and;
- developing international guidelines to address the problem of invasive alien species under the CBD (European Commission 1998).

The EU has ratified a number of other international conventions aimed at the prevention, management and control of invasive alien species. They include agreements under the European and Mediterranean Plant Protection Organization and WTO. Under the IPPC, the European and Mediterranean Plant Protection Organization (EPPO; http://www.eppo.org/; accessed July 10, 2006) is the intergovernmental organization responsible for cooperation in plant protection in the region. From 15 member countries when it was founded in 1951, EPPO has grown to include 47 member countries in 2005. EPPO's goal is to help member countries prevent entry and spread of invasive alien species, identify those that may present a risk, and put forward proposals on new phytosanitary measures.

The European Strategy on Invasive Alien Species, introduced in 2003, recommends surveillance for all taxonomic groups and focus on high-risk sites, such as main entry points for commercial and tourist arrivals, entry points of natural dispersal pathways, areas adjacent to facilities where alien species are kept in captivity or containment, and areas where severe disturbance has already occurred (Genovesi and Shine 2004).

In terms of communication, a recently compiled European Information System on Invasive Alien Species, also known as Regional Biological Invasions Centre (http://www.zin.ru/rbic/default.asp. Accessed November 23, 2006), is a web portal that provides access to European information on biological invasions since 2001.

Australia and New Zealand

In both Australia and New Zealand, forest-related industries make considerable contributions to the national economies. In 2005, log supply from Australia's plantations was close to 18 million m^3 and supply from New Zealand's forest plantations was estimated at 18.9 million m^3. Plantations are susceptible to attack by invasive alien species because most of the trees planted are non-native, whereas native forests are unprepared to compete with alien organisms because they have evolved in the context of the countries' natural ecological and geographic isolation (Wylie 2001). Maintaining the health of plantation and natural forests is important to ensure both productivity and ecological functions.

Australia

The key institutions addressing the introductions of invasive alien species to forest ecosystems in Australia are the Australian Quarantine and Inspection Service (AQIS), Biosecurity Australia and Plant Biosecurity Australia.

The AQIS (http://www.aqis.gov.au/; accessed July 10, 2006), part of the Department of Agriculture, Fisheries and Forestry Australia (AFFA), provides quarantine inspection of international passengers, cargo and mail, animals and plants, and their products arriving in Australia. AQIS also inspects and certifies a range of agricultural and forestry products exported from Australia. Quarantine controls at Australia's borders aim to reduce the risk of invasive alien species affecting Australia's industries and environment. AQIS's responsibilities include ensuring border quarantine security, issuing import permits and providing export health certification.

Biosecurity Australia (http://www.affa.gov.au/biosecurityaustralia; accessed July 10, 2006), also part of AFFA, was established in October, 2000, to separate the development of biosecurity policy from the operational work of AQIS. Biosecurity Australia provides science-based quarantine assessments and policies to protect the country from invasive alien species. It is responsible for

- developing new biosecurity, including sanitary and phytosanitary, measures and reviewing existing measures for the importation of live animals and plants, and their products;
- working with AQIS to implement biosecurity measures;
- conducting negotiations with agencies in other countries to improve existing market access and develop new market access for Australian animals and plant products;
- participating in international activities relevant to biosecurity, and;
- working with various national, state and territorial organizations in relation to biosecurity.

Plant Biosecurity, an agency within Biosecurity Australia, deals specifically with policies to protect Australia's horticultural industries and the natural environment from invasive alien organisms. This division of Biosecurity Australia also addresses alien species that may become a threat to forests.

Because invasions of alien organisms could be disastrous for Australia's forest ecosystems and forest sector, risk analysis is undertaken for each import requested and follows the import risk analysis process (AFFA 2003). Regarding communication and public education, several Australian agencies have jointly published a field guide to alien forest pests and diseases (AFFA 2000) that features important examples of alien insects and diseases that could damage Australia's environment. The guide is aimed at port workers, container depot staff, timber handlers, forest workers, and forest technical staff. It also lists whom to contact if an alien organism or sign of an alien disease is spotted.

The Australian Standing Committee on Forestry commissioned an independent evaluation of the significance of introduction of new alien invaders into the country, as well as the development of an action plan for eradication (Gadgil 2000a; 2000b). This study produced a review of Australia's current (as of 2000) plan for managing incursions of alien forest pests and pathogens, and formulated recommendations to reduce the risk of incursions and to improve the chances of early detection. A recommendation regarding quarantine may be of interest to Canada: "Specialist advice in forest pathology and forest entomology should be available to quarantine inspectors" (Gadgil 2000b). The report also recommended that the costs of border inspection to identify forest insects and pathogens should be "shared between importers, overseas passengers, primary industries including forestry and the Commonwealth and State Governments."

The recommended management plan followed the existing pre-border quarantine measures that aim to exclude pests and is intended to facilitate rapid response when a potentially serious forest pest has been detected within the country. The key element in the defense against introductions of alien species into Australia is quarantine exclusion based on sound scientific knowledge and study of likely entry pathways. Complete exclusion of undesirable aliens is never possible, but when introductions do occur, the country requires easily understood and well-coordinated response mechanisms to be in place (Gadgil 2000a).

New Zealand

Biosecurity New Zealand (http://www.biosecurity.govt.nz/; accessed July 10, 2006), a division of the New Zealand Ministry of Agriculture and Forestry (MAF), leads prevention of imports of unwanted alien organisms, and their control, management or eradication once they arrive.

New Zealand is strongly motivated to prevent forest invasive alien species from becoming established. The establishment of an alien invader could result in the economic devaluation or depletion of valuable Radiata pine plantations, reduced recreational and amenity values of indigenous forests, loss of biodiversity, international export restrictions on forest products, and an increase in economic, environmental and social costs.

Biosecurity New Zealand addresses the risk of invasive alien species associated with the importation of used vehicles, goods imported in containers, and air cargo imports. It also handles revisions of import health standards for forest products, seeds and nursery stock to address the threat of forestry pests and diseases, and ensures that quarantine measures in the forestry area conform to the IPPC and WTO-SPS measures.

An increasing volume of trade and travel is increasing pressure on New Zealand's biosecurity systems. All imported wood products are inspected on arrival. Some commercial shipments of wood products must be treated before entering New Zealand. A certificate confirming the type and method of treatment must accompany goods treated overseas. All other imported goods are also subjected to either pest or import risk analyses (Biosecurity NZ 2003a).

Border inspections for the clearance of commodities of risk to forests are predominately self-funded through charges on importers. Costs related to border inspection of imported and exported goods are grouped into several categories:

- inspection of documents, identification of organisms and discharge of goods;
- monitoring, verification and inspection of shipping containers, and offshore inspection of ships;
- inspections of unaccompanied baggage or effects;
- inspection of vehicles, vehicle parts, tires and machinery;
- inspection of animals or animal material;
- inspection of plant material (except forestry products);
- inspection of forestry products, including sawn wood, logs and roundwood;
- treatment, destruction, or disposal of risky goods;
- permits issued under import health standards;
- transitional and containment facilities, and;
- other provisional costs such as travel costs and waiting time (Biosecurity NZ 2003b; 2003c).

New Zealand's early detection and monitoring programs are funded jointly by the Ministry of Agriculture and Forestry, the Department of Conservation and the Forest Owners' Association. The New Zealand Ministry of Agriculture and Forestry is in charge of surveying port environments and high-risk sites. The New Zealand Forest Owners' Association funds monitoring aimed at detecting new incursions in forest plantations. Industry-funded surveillance programs include ground and aerial surveys of commercial exotic and indigenous forests, as well as surveys of forest nurseries and seed orchards. In addition, the New Zealand Department of Conservation funds limited surveys of the conservation estate.

6. Recommended measures for dealing with invasive alien species

Although current efforts by many countries for dealing with invasive alien species are effective in particular cases, they are unsuccessful in controlling the general problem. This failure at the international, regional and national levels results from insufficient enforcement, inadequate research and management funding, lack of collaboration, and gaps in scientific knowledge and public education (Simberloff et al. 2005).

Canada is very vulnerable to invasions of newly introduced and already-established alien species. Several measures are recommended to improve protection of Canada's forest ecosystems and the forest sector from future damages caused by invasive alien species.

Research and enforcement needs

Research and experience show that identifying deliberate and accidental entries of new invasive alien organisms into the country is technically feasible. Investment in research, prevention, detection, and early eradication and restoration of ecosystems affected by invasive alien species may minimize the number and cost of invasive outbreaks (Simberloff et al. 2005; Berenbaum 2001). However, comprehensive programs require significant funding.

The CFIA surveillance programs are currently able to inspect only a small fraction of commodities imported to Canada for alien species (Collauti et al. 2006; Perrault et al. 2003). The agency also conducts pest risk analyses, the values of which depend greatly on quality of the ecological information on target pest species and their economic significance. However, obtaining necessary data is expensive and time-consuming, as has been proved by the high costs of several USDA pest assessment studies on the import of raw wood (Wallner 2004). Without additional resources, it will be difficult to implement successfully the Canadian strategy against invasive alien species.

It is difficult to suggest an appropriate investment for research, prevention of introduction, and control of established invasive alien species in Canada. Such a suggestion would require analysis using complex economic models to estimate the efficiency of such an investment (Colautti et al. 2006). New Zealand studies have found that small reductions in the establishment rate of new alien forest organisms can provide large economic returns (Turner et al. 2004; Kriticos et al. 2005), because of the high costs of managing alien invaders in forests (Case 2.7): analysis of the returns on investment in border biosecurity improvement estimated that NZ$25 million invested into improvement could return NZ$87 million over 12 years in direct net economic benefits to the country (Kriticos et al. 2005). The New Zealand studies analyzed costs and benefits of improved biosecurity measures; no published study with regard to optimal investments in these measures exists.

Cost-effective prevention and control

Deliberate introductions of alien species are often economically motivated by expected financial gains for the proponent of the imported species or commodity. Because of the potentially huge socioeconomic and environmental consequences to society as a whole, an appropriate cost–benefit analysis is recommended for each proposed import. Costs must be weighed against the positive benefits of the prevention and control measures. The costs involved are:

- the costs of risk assessment and cost–benefit analysis itself;
- the inspection and control costs, including the salary and training of personnel, treatment and quarantine facilities. Wallner (2004) reports the high costs of several USDA pest assessment studies regarding the import of raw wood into the U.S. and;
- the loss of importers' surplus, plus loss of consumer surplus.

The last and indirect costs arise from trade disruptions caused by inspections that could take place at the pre-border, border or post-border stages. The potential benefits of the management measures are:

- avoided loss of timber and other wood products (resource rent);
- avoided loss of producer surplus in wood-processing sectors;
- avoided loss of environmental amenities related to recreation, viewing, hunting and water quality;
- avoided costs of restoration of damaged ecosystems, and;
- avoided costs of managing pests.

Cost–benefit analyses could also support decisions regarding allocation of scarce resources to management options against invasive alien species. This technique could be used to rank potential returns from investments into research, prevention, monitoring and control. In the light of scarce resources, securing necessary resources for early and effective control can be difficult. Given this challenge, future efforts to counter threats of invasive alien species will need to communicate effectively the cost-effectiveness of prevention compared to the high cost of eradication.

Collaboration and information sharing

The problem of invasive alien species is so large, it cannot be properly dealt with unless groups and countries work together to find solutions. Invasive alien species may pose problems across multiple sectors and areas within one country, but because alien species do not recognize borders, they must be dealt with at local, national, regional and international levels simultaneously. In Canada and the U.S., national forest services collaborate closely with quarantine regulatory agencies, but the forestry sectors should be more involved in prevention, particularly in the risk-analysis process. In addition, the issue of invasive alien species needs to be dealt with beyond the forest services and quarantine regulatory agencies: other government agencies, including those involved with trade and transportation, should be involved (Perrault et al. 2003).

A number of countries, including Canada, have created national strategies and action plans for dealing with invasive alien species through the collaboration of multiple government agencies. In addition, many government and non-government groups run projects to monitor and control invasive alien species. To avoid fragmentation of efforts, government and non-government projects across sectors need to collaborate and share information. For instance, collaboration between universities and government agencies on this issue could yield valuable results and should be explored further.

The issue of invasive alien species is notorious for uncertainty and lack of reliable data. Coordinated data collection requires additional funding; the return on investment would be reduced uncertainty relating to introduction and reduced spread of invasive alien species. In addition, data sharing would increase the amount of data available and reduce costs of data collection.

The requirement for data sharing includes using global databases for monitoring invasive species. Global databases could provide early warning of potential invasive species problems. Their effectiveness would require timely coordination and distribution of information regarding threats and adequate response, and should include results of species- or pathway-risk analyses.

Use of existing models and risk assessment protocols

Several countries have developed, tested, evaluated and applied decision-support models or risk assessment protocols for dealing with certain invasive alien species. Canada could adapt existing tools that have proven cost-effective in other countries with similar problems with invasive alien species. For example, the Australian–New Zealand Weed Risk Assessment protocol was adapted and evaluated for use in Hawaii (Denslow and Daehler 2004). The original protocol was designed to screen plants proposed for introduction into Australia and New Zealand; Hawaii did not require such an evaluation of imported plants, but needed a means to evaluate alien plants already present in the state. The State of Hawaii has adapted the protocol to evaluate plants already introduced and used in landscaping and forestry, and to predict the likelihood of these plants having adverse ecological and economic impacts.

An example of how existing tools could be adapted to predict geographic distribution of potential forest pests and pathogens across Canada is the new application of BioSIM (Régnière 2003). The software tool, BioSIM, developed at the Canadian Forest Service's Laurentian Forestry Centre, has been applied to examine gypsy moth invasive capacity west of Ontario, as particular regions within the country may be more vulnerable to gypsy moth than others and require specific regulations (Régnière et al., in press).

Measures based on species white list vs. black list

Despite increased attention directed at invasive alien species, current prevention measures in many countries, including Canada, target species already identified as pests either in the country or elsewhere; i.e., black-listed species. The black-list approach initiates risk analysis for the introduction and spread of an alien species that has already been invasive elsewhere. This rather conservative approach leaves the door open for many organisms to enter into the country undetected.

Australia and New Zealand have adopted a different legislative strategy by addressing species on the white list that are not known to be invasive and are specifically permitted for import. Inspections should be based on a list of all species that are regarded as potential threats to forests or the forest sector. This approach is often called "guilty until proven innocent" (Cambell 2001). Each alien species or commodity proposed for import is assessed by risk analysis, and then is added to either the white list or black list, depending on assessment outcomes. The white list contains those species that have been cleared for introduction through risk analyses; these species should be reassessed at regular intervals.

Although the proposed "guilty until proven innocent" principle makes sense scientifically, it may pose significant challenges to regulatory agencies, both in terms of its cost and feasibility.

Public education

Many people in Canada are unaware of alien species and their potential negative effects, are not vigilant for signs of alien species, and are sometimes even responsible for deliberate or accidental introductions. Public education, therefore, constitutes an important measure for prevention and control. In the long run, informing people of the actions they may take to reduce threats by invasive alien species may be more cost-effective than enforcing regulations.

Publications and a variety of education and outreach programs are needed to raise awareness in Canadians about the issue. This awareness will more likely help people make better decisions about preventing and dealing with this problem (Claudi et al. 2002). Although government agencies need to play a key role in the development and support of public education programs, actions to minimize spread of invasive species are undertaken by the public: individuals, businesses, non-governmental organizations and conservation organizations. As with other recommended measures, public education requires long-term funding, staffing and appropriate infrastructure—all resource challenges.

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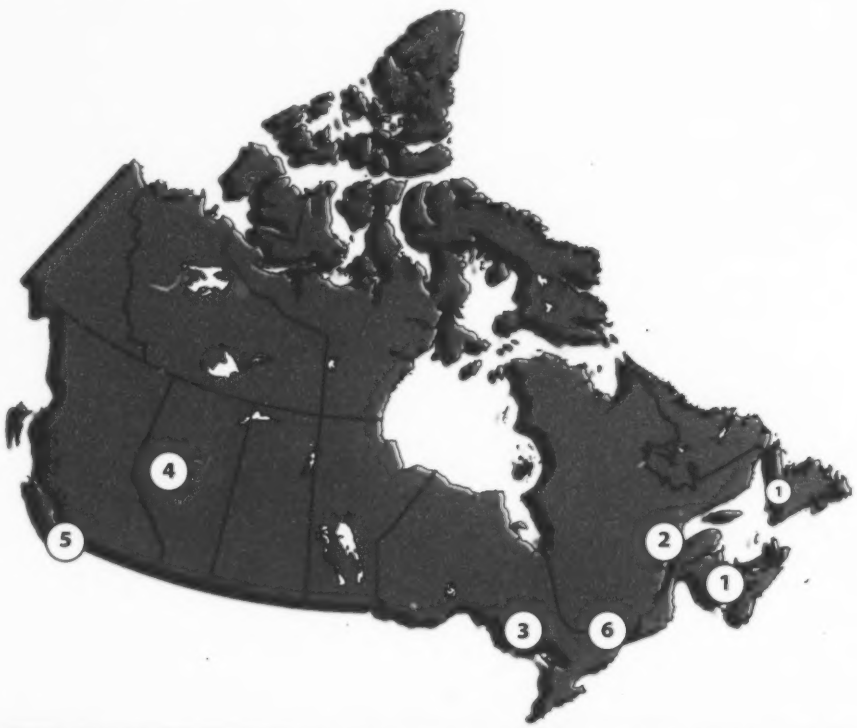

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